The Helicity Asymmetry Measurements for π^0 photoproduction with FROST

Hideko Iwamoto

The George Washington University

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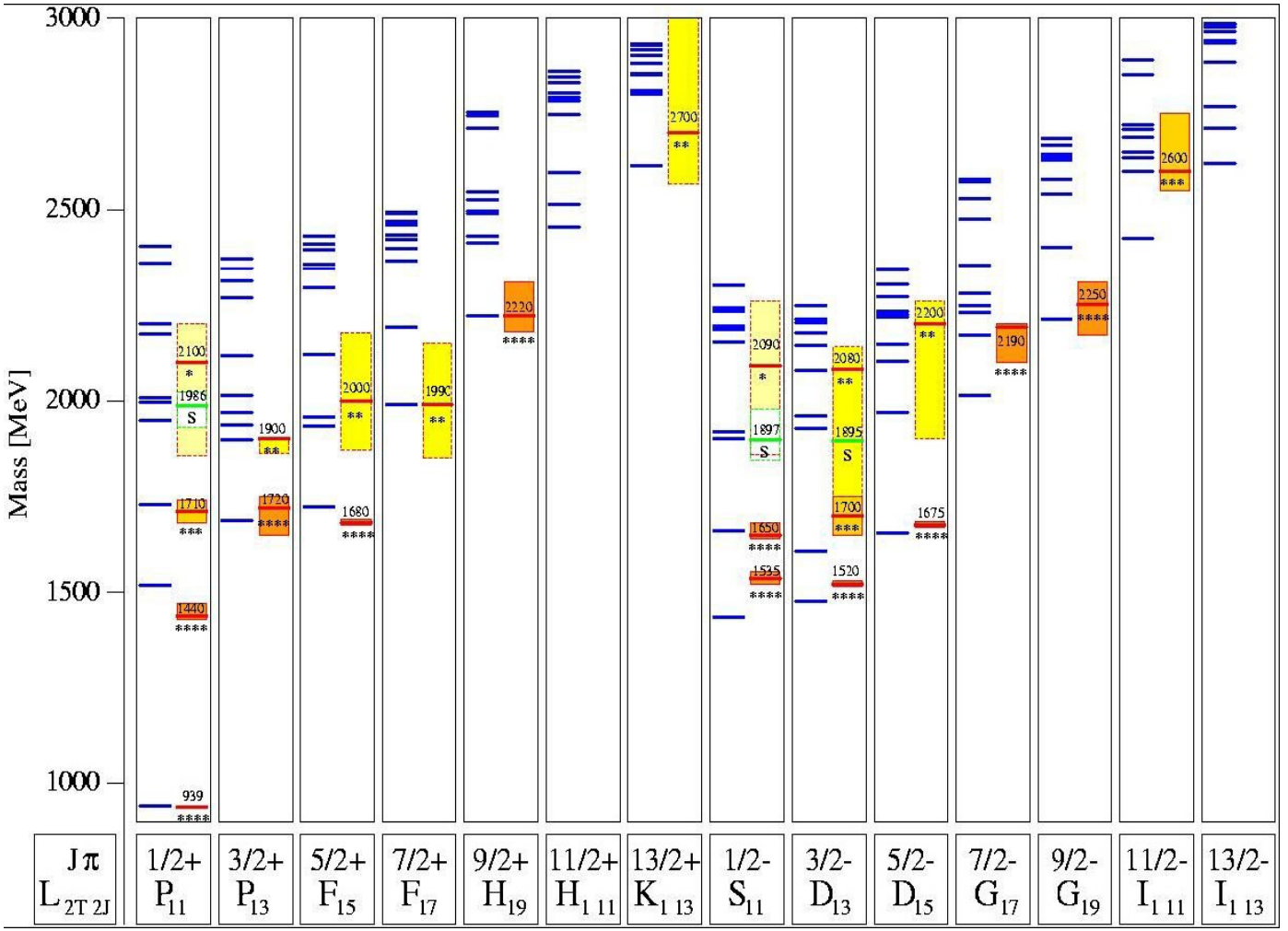
Outline

1. Motivation
   nucleon resonances
2. FROST Experiment
   beam, target, polarization
3. Analysis
   normalization and dilution factors
   comparison with models, MAMI data

Baryon Resonance

N* and Δ* by Quark model

Mass, width, couplings to various modes are not well known



FROST (FROzen Spin Target)

Photon	Target				Recoil			Target + Recoil			
	–	–	–	–	x'	y'	z'	x'	x'	z'	z'
	–	x	y	z	–	–	–	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	-$L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	(-P)	$-G$	$O_{x'}$	(-T)	$O_{z'}$	(-$L_{z'}$)	($T_{z'}$)	(-$L_{x'}$)	(-$T_{x'}$)
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

Study of exited nucleon states (N* and Δ*)

→ Understand the structure of the nucleon

→ Analyze decay products due to short lifetime

analysis of π, η, K, Λ, Σ with FROST

Double polarization experiments are important

Helicity Amplitude

Helicity $$H = \frac{\vec{p}\cdot\vec{s}}{|\vec{p}||\vec{s}|}$$

Property:

invariant under the rotation

parity and four momentum are conserved

	$\lambda_k = +1$		$\lambda_k = -1$	
$\lambda_f \backslash \lambda_i$	3/2	1/2	-1/2	-3/2
1/2	H_3	H_4	$-H_2$	H_1
-1/2	H_1	H_2	H_4	$-H_3$

λ_k : spin of photon

λ_i : total initial spin

λ_f : total final spin

$$E = \{|H_1|^2 - |H_2|^2 + |H_3|^2 - |H_4|^2\}/(2\,I(\theta))$$

Spin Observable

H_1, H_2, H_3, H_4 determined by
8 carefully selected measurements

F.Tabakin, W.Choang Phys. Rev. C55, 2054 (1997)

Double polarized beam and target:

$$\frac{(d\sigma)}{(d\sigma_0)} = 1 - P_T \Sigma \cos(2\phi) - P_x (P_T H \sin(2\phi) - P_c F)$$
$$+ P_y (T - P_T P \cos(2\phi)) + P_z (P_T G \sin(2\phi) - P_c E)$$

Partial Wave

Helicity Amplitudes

$$H_1 = \frac{-1}{\sqrt{2}} \sin\theta (F_3 + F_4 \cos\theta) \qquad H_3 = \frac{-1}{\sqrt{2}} F_4 \sin^2\theta$$

$$H_2 = \frac{-1}{\sqrt{2}} (2F_1 - 2F_2 \cos\theta + F_4 \sin^2\theta) \qquad H_4 = \frac{1}{\sqrt{2}} \sin\theta (2F_2 + F_3 + F_4 \cos\theta)$$

CGLN Amplitudes

$$F_1 = \sum_{l \geq 0} [(M_{l+.} + E_{l+.}) P'_{l+1} + [(l+1) M_{l-.} + E_{l-.}] P'_{l-1}]$$

$$F_2 = \sum_{l \geq 1} [(l+1) M_{l+.} + l M_{l-.}] P'_l$$

$$F_3 = \sum_{l \geq 1} [(E_{l+.} - M_{l+.}) P''_{l+1} + (E_{l-.} + M_{l-.}) P''_{l-1}]$$

$$F_4 = \sum_{l \geq 2} (M_{l+.} - E_{l+.} - M_{l-.} - E_{l-.}) P''_l$$

Lagrangian density for π^0p

$$L_{\gamma pp} = e \bar{\psi}_p [F_1^p(0) \gamma^\mu A_\mu - \frac{F_2^p(0)}{2m_p} \sigma^{\mu\nu} \partial_\nu A_\mu] \psi_p$$

$$L_{\pi^0 pp} = -i \frac{f_{\pi pp}}{m_\pi} \bar{\psi}_p \gamma^\sigma \gamma^5 \psi_p (\partial_\sigma \pi^0)$$

Asymmetry E and G
(Nov.3, 2007 ~ Feb. 12, 2008)

Photon beam

- Circularly and linearly polarized
- 0.5 ~ 2.4 GeV (electron beam 1.645 & 2.478 GeV)

Target

- Butanol (C_4H_9OH)
- 78 ~ 92% of polarization

Production

Circularly polarized beam

1.645 GeV 1.1 Billion trigger

2.478 GeV 2.3 Billion trigger

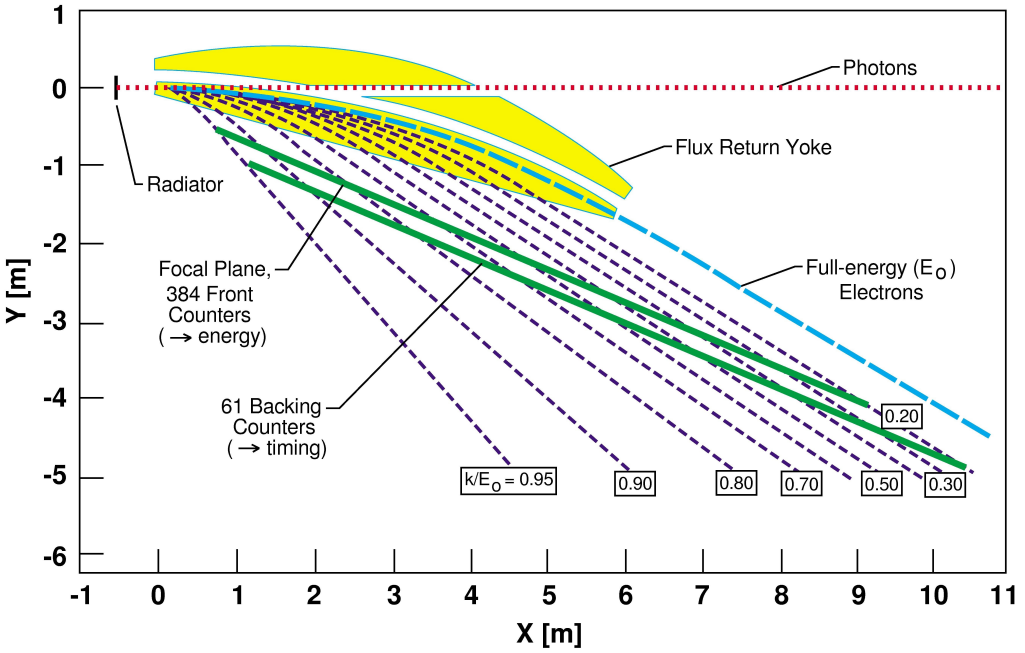
*trigger: at least one charged particle in CLAS

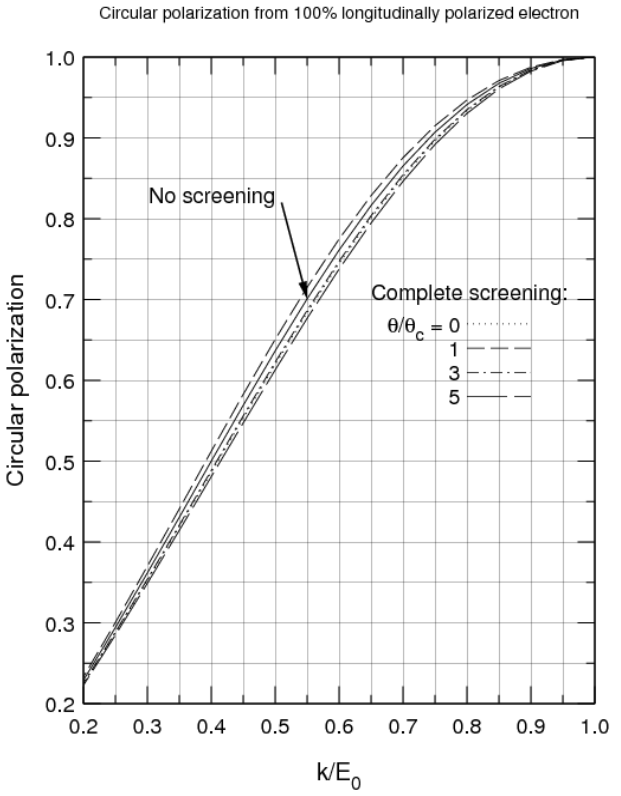
Circularly polarized photon beam

Bremsstrahlung use linearly polarized electron beam

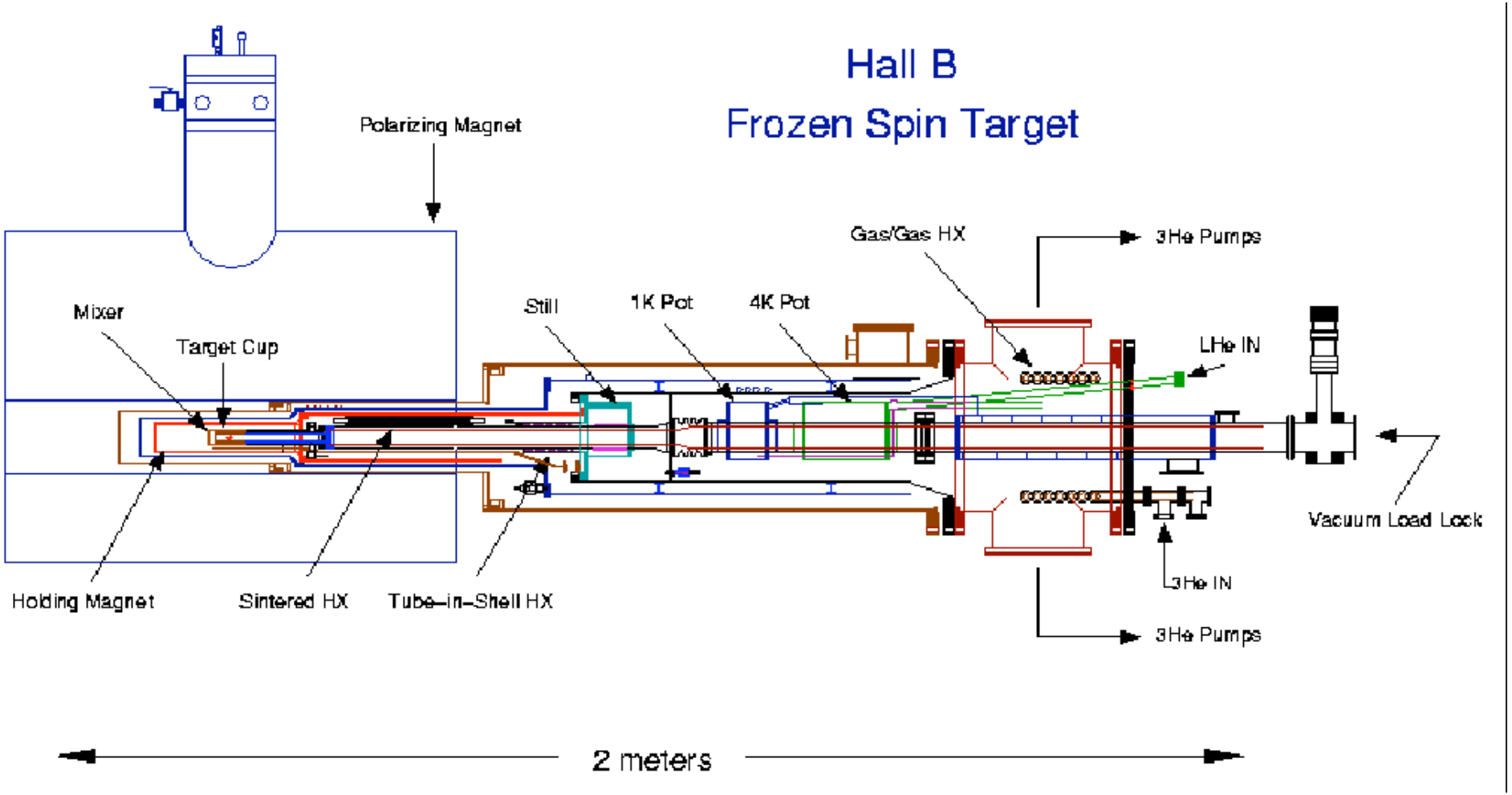
$$P(\gamma) = P(e)\frac{4x - x^2}{4 - 4x + 3x^2}$$

$$x = \frac{k}{\epsilon_1} = \frac{(photon\ energy)}{(incident\ electron\ energy)}$$

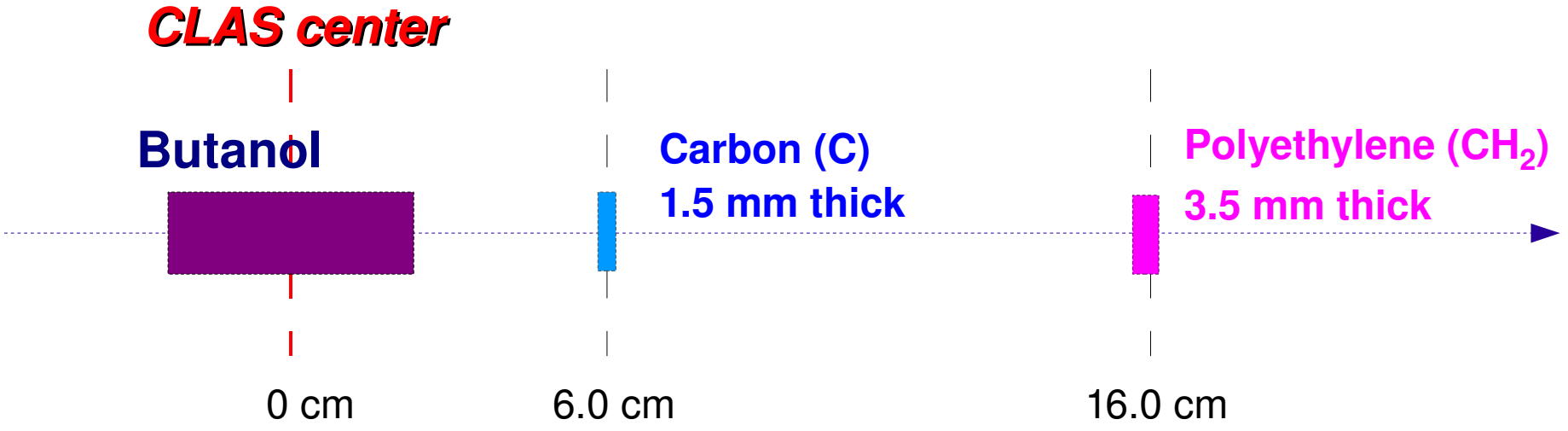




Target


Hall B
Frozen Spin Target
Polarizing Magnet
Gas/Gas HX
3He Pumps
Mixer
Target Cup
Still
1K Pot
4K Pot
LHe IN
Vacuum Load Lock
3He IN
Holding Magnet
Sintered HX
Tube–in–Shell HX
3He Pumps
2 meters

Target



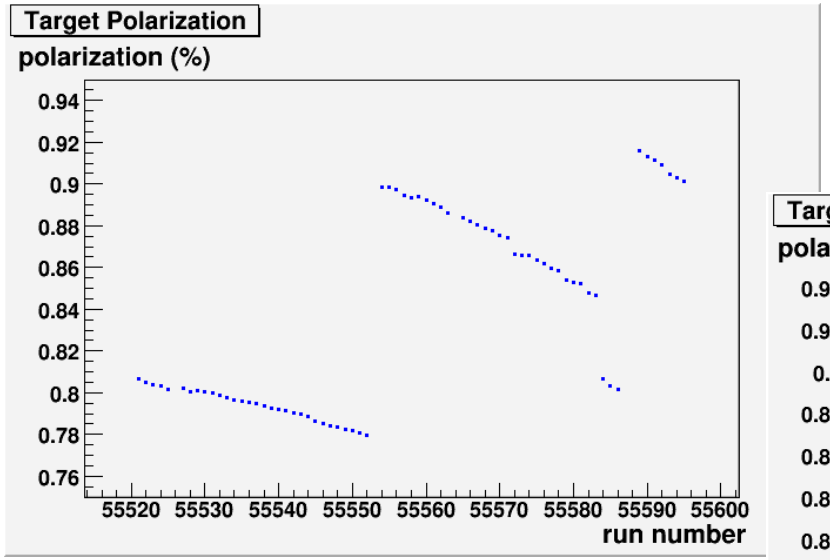
Butanol(C_4H_9OH)

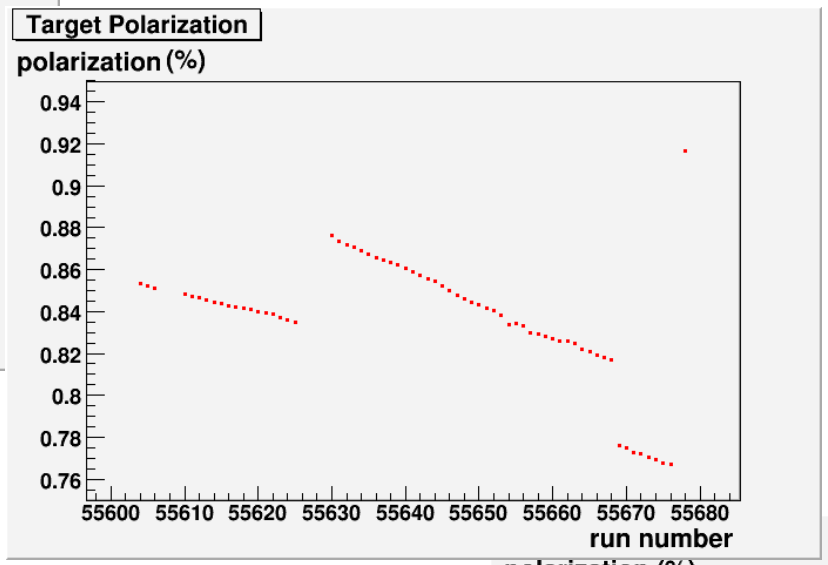
Dynamic Nuclear Polarization (DNP)

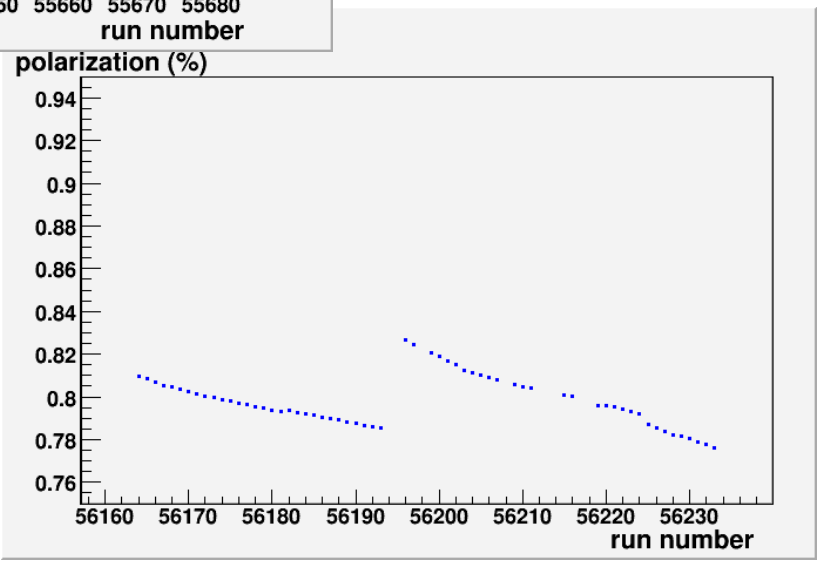
length 50mm / diameter 15mm

Holding mode (0.5T, 28 ~30 mK)

Polarization of target

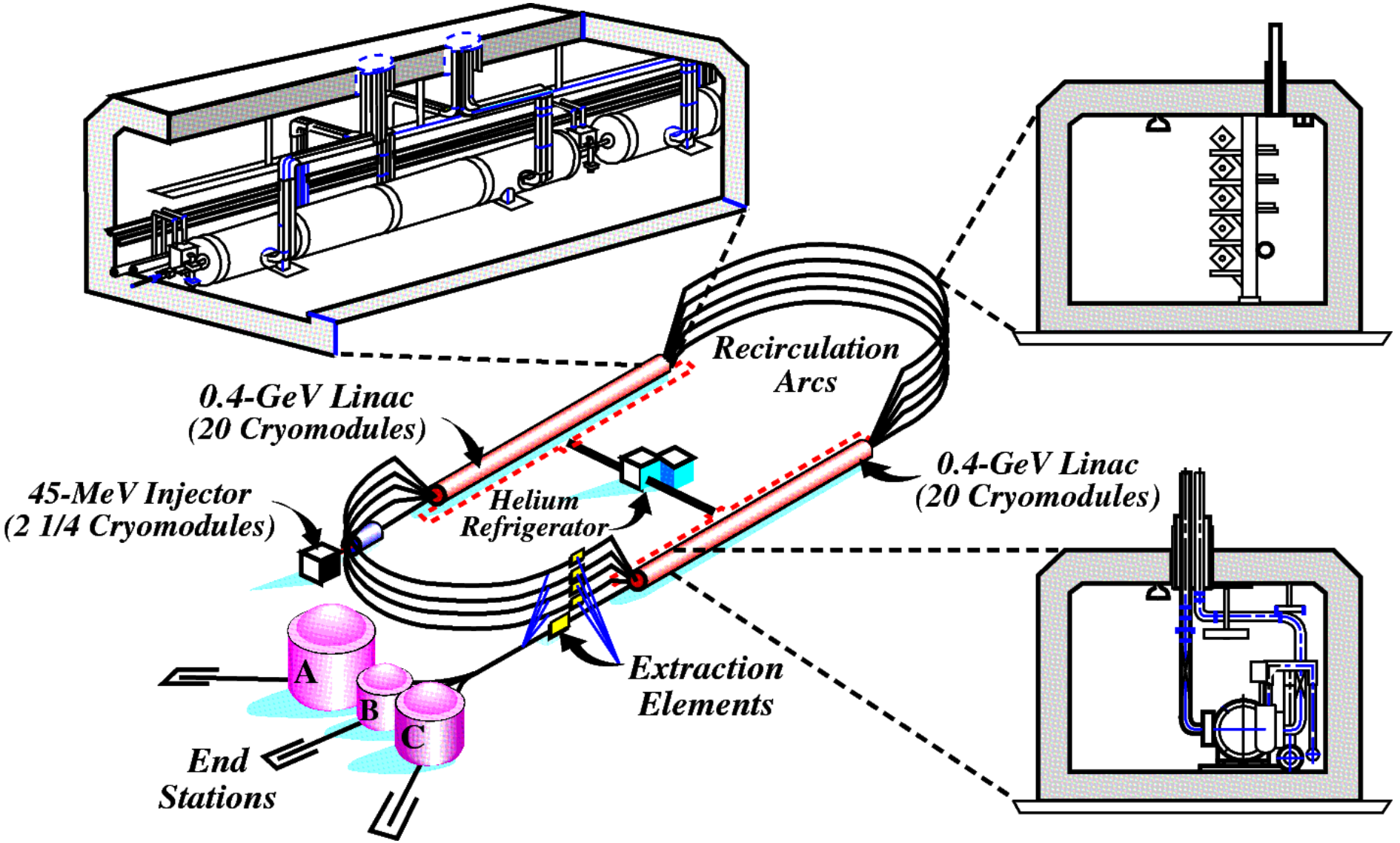






P_T = 78 % ~ 92 %

CEBAF accelerator



CLAS (CEBAF Large Acceptance Spectrometer)

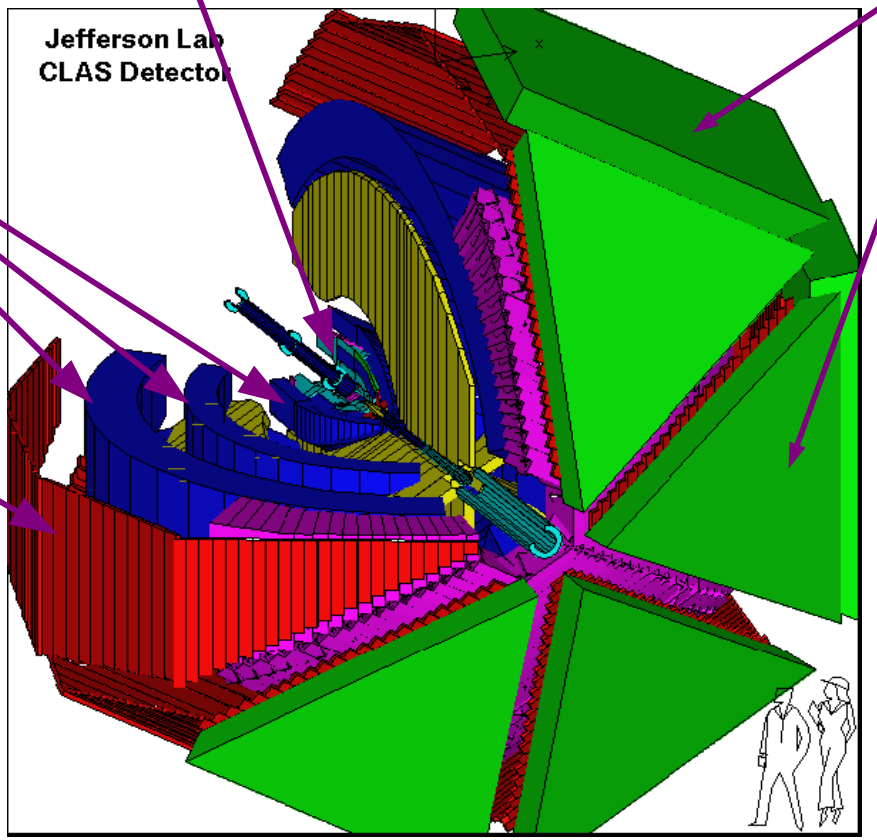
Target

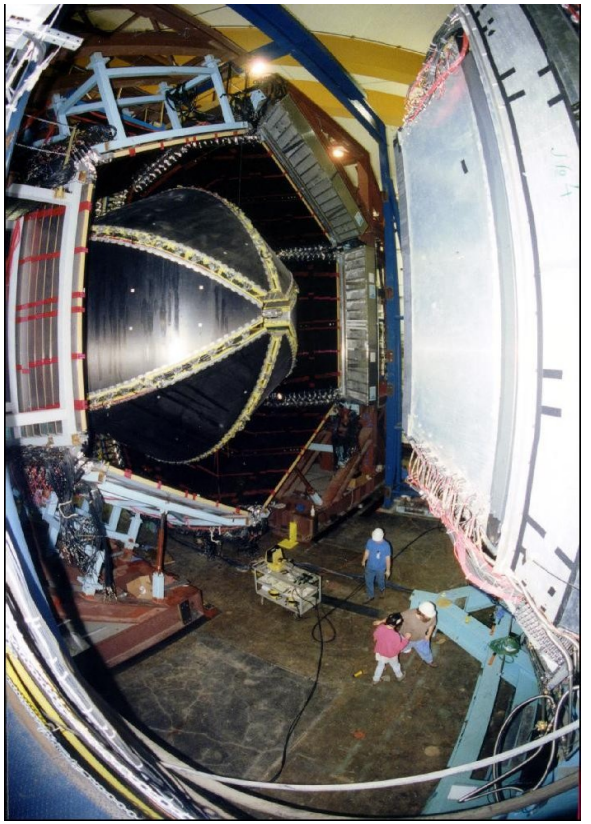
Electromagnetic calorimeters

Drift chambers

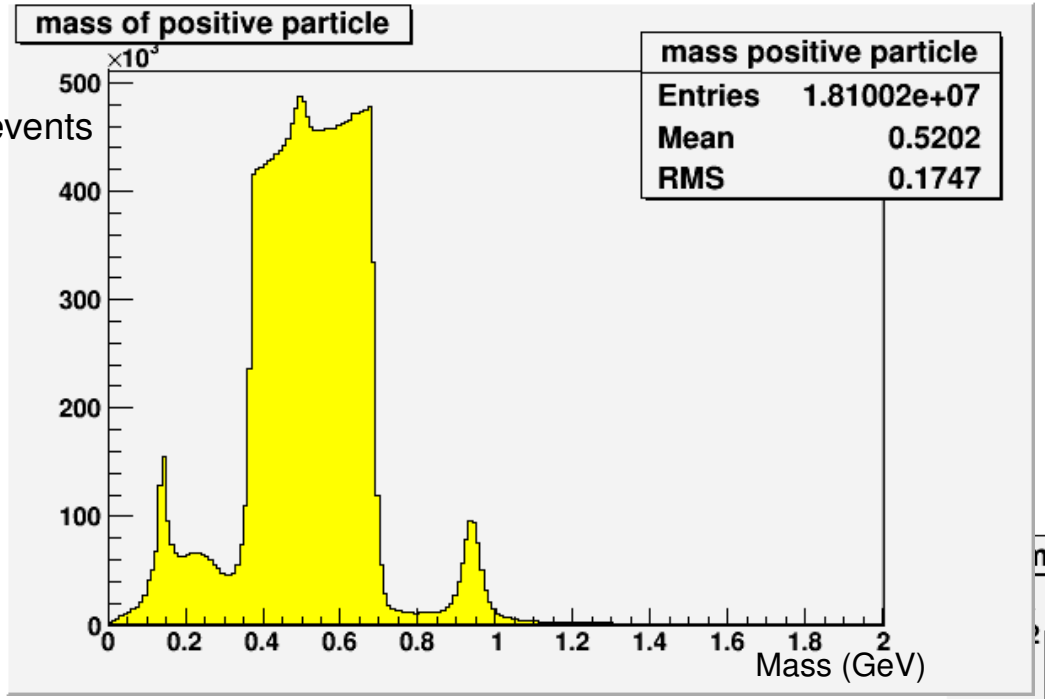
Time-of flight counters

Region 1

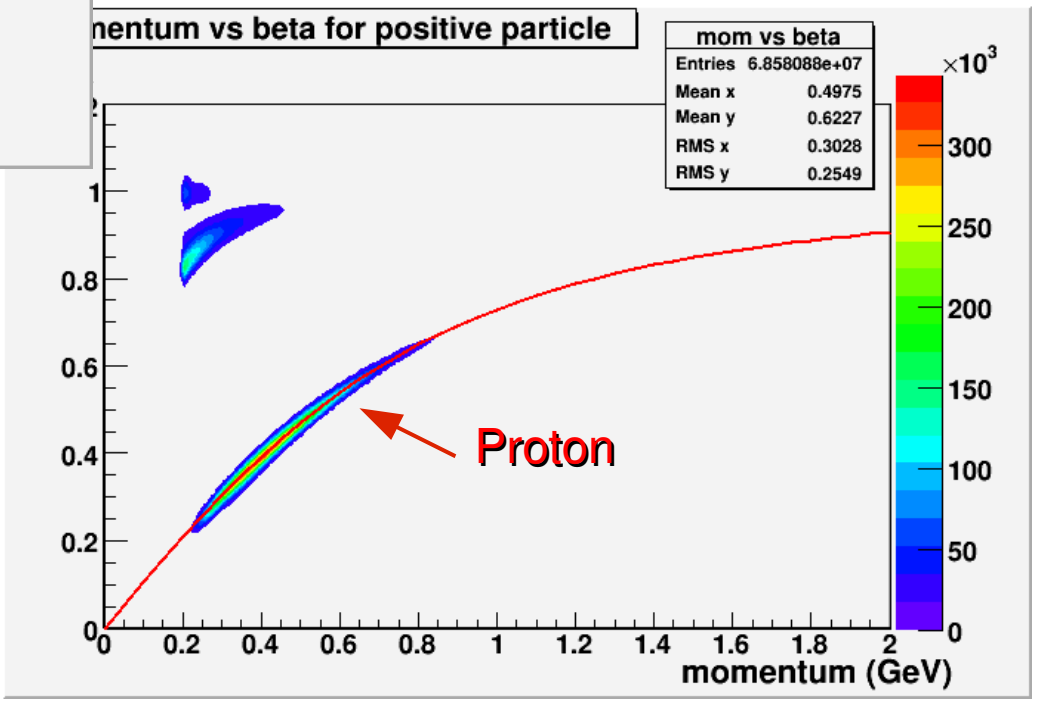




Event selection and particle ID



Drift Chamber hit
Start Counter hit
TOF counter hit
&
One positive particle



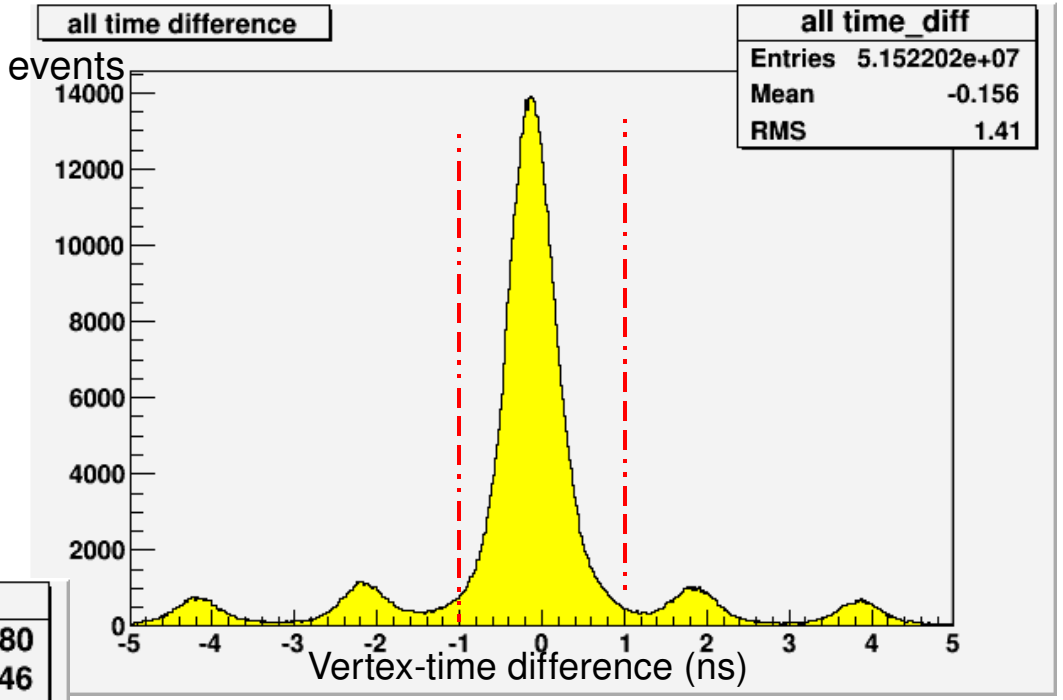
Event selection 2

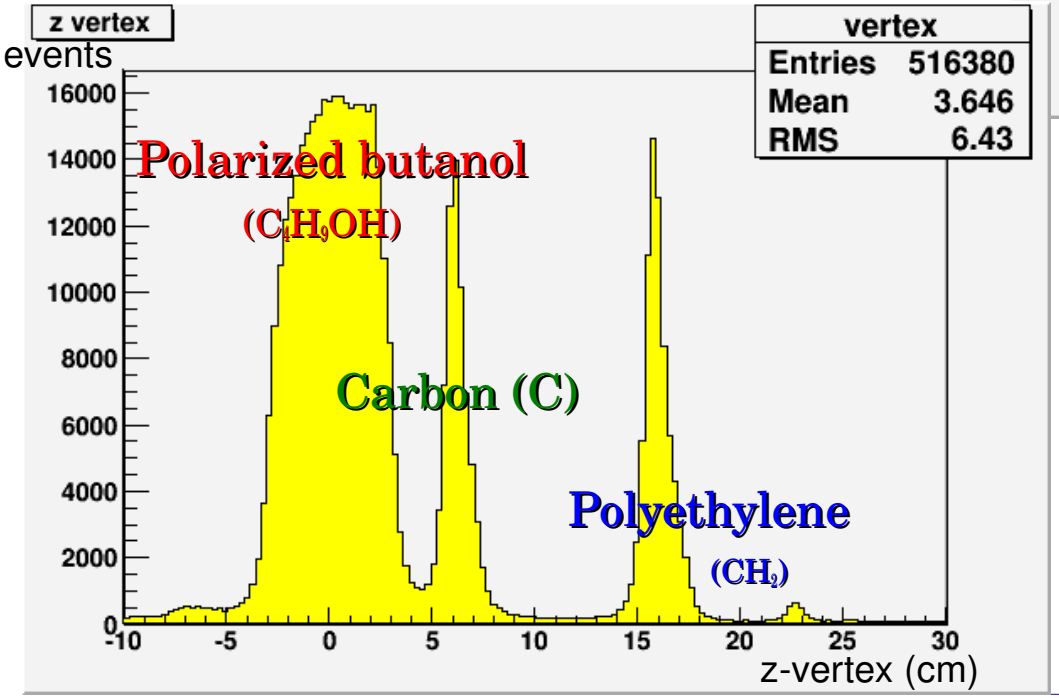
Choose proton by beta

&

Time difference < 1.0 ns

(choose good photon)





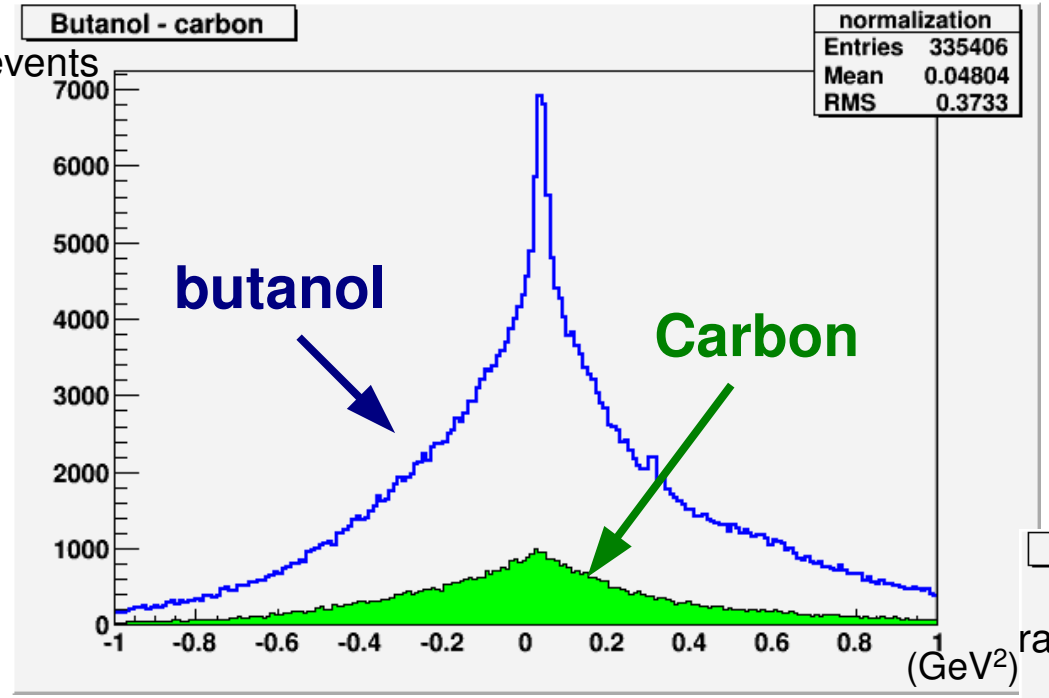
Thickness of targets

Butanol 50.0 mm

Carbon 1.5 mm

Polietilen 3.5 mm

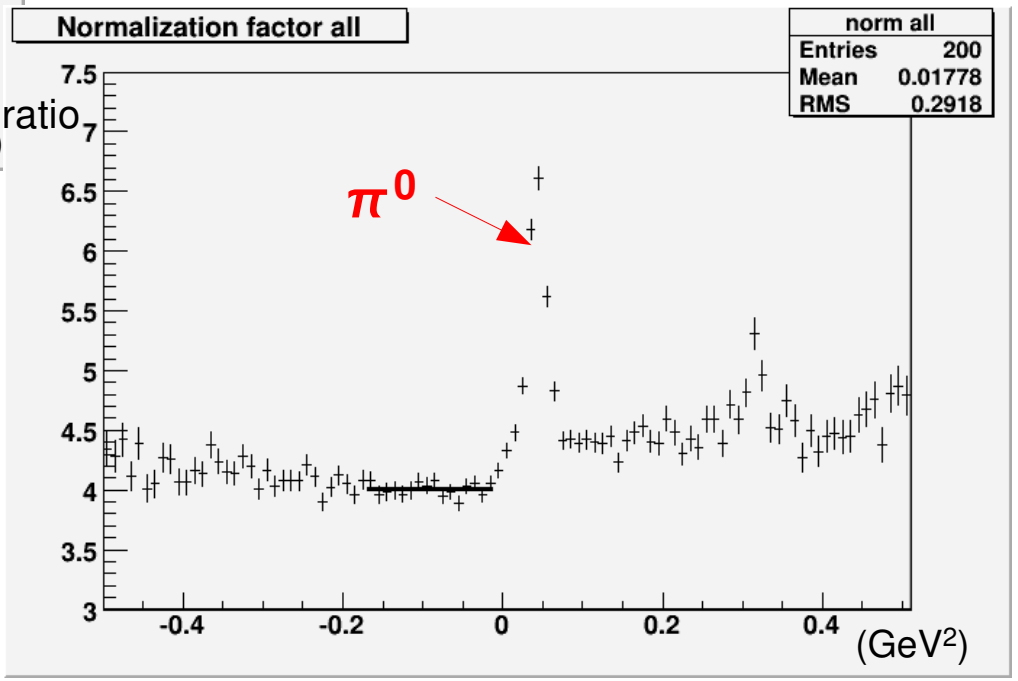
Normalization factor



Remove background

(reaction from bound nucleon)

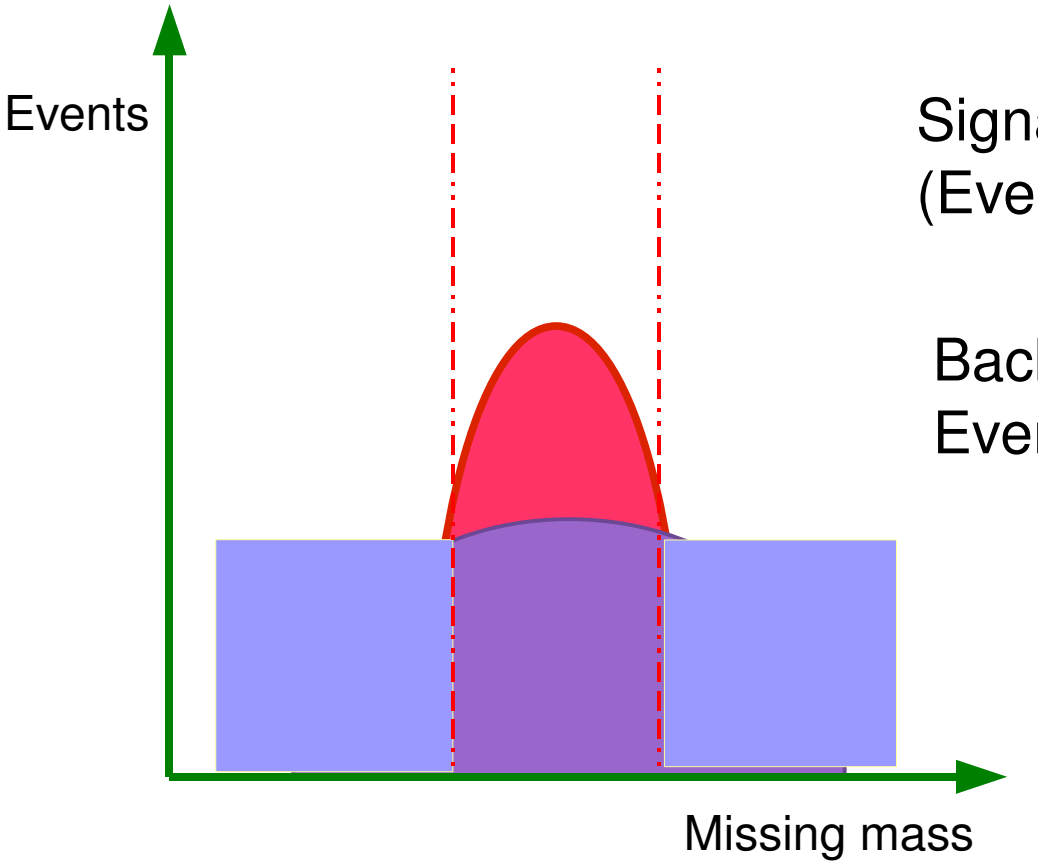
Use carbon target



Normalization factor

≃ 4.16

Dilution factor

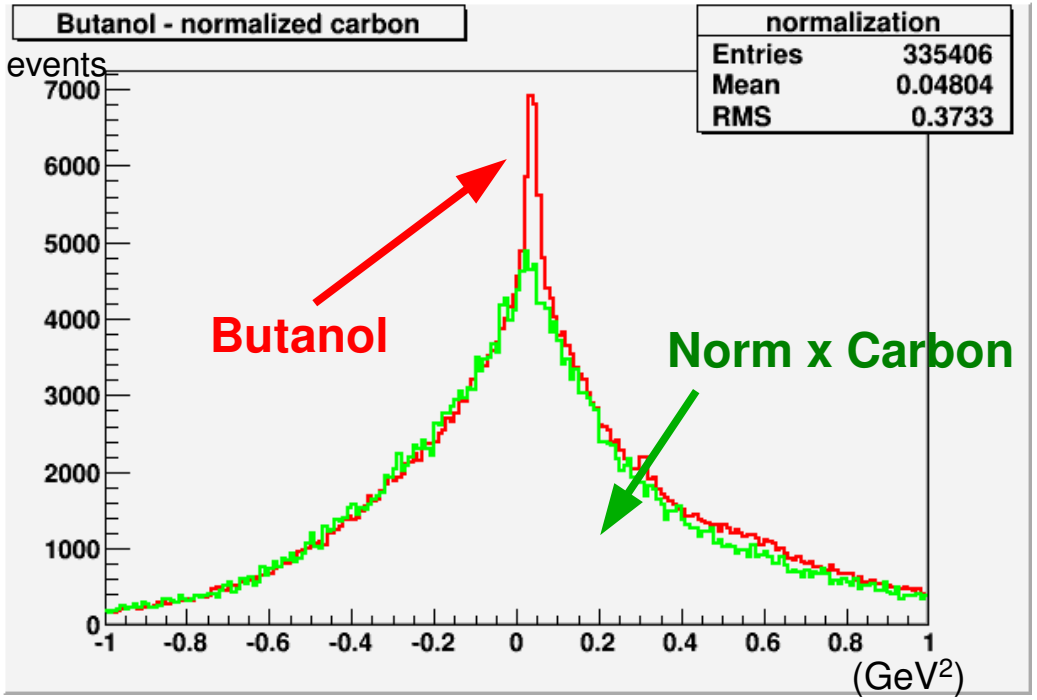


Signal
(Events from free proton)

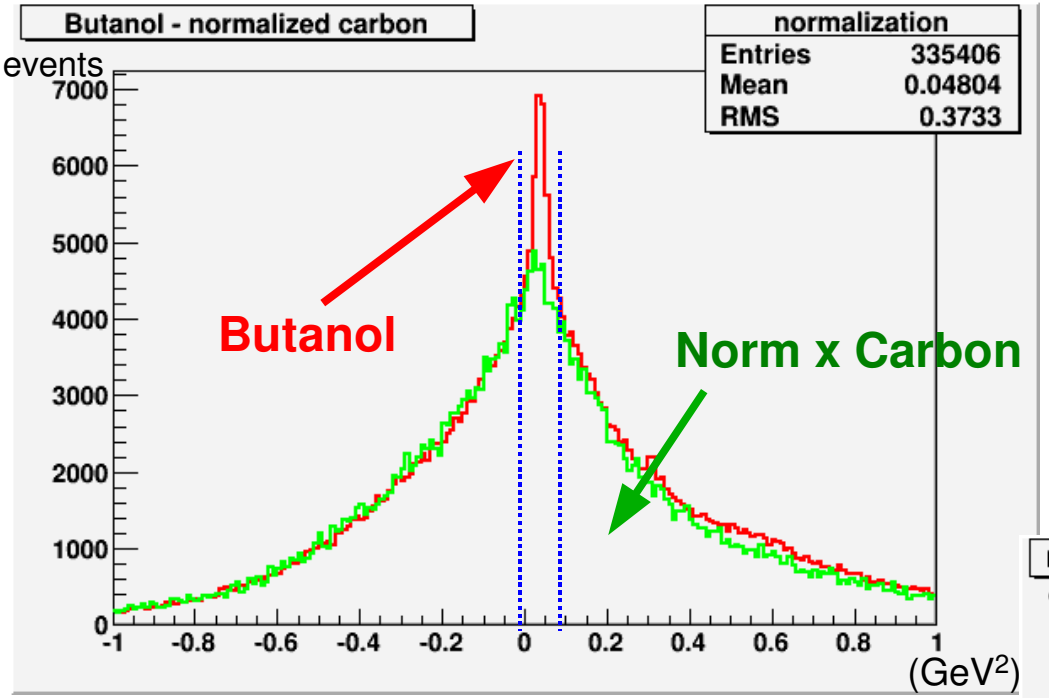
Background
Events from bound nucleon

$$\text{Dilution factor} = \frac{\text{Free proton}}{\text{Free proton} + \text{Bound nucleon}} = 1 - \frac{\text{Norm} \times \text{Carbon}}{\text{Butanol}}$$

γ(p, p)X missing mass square

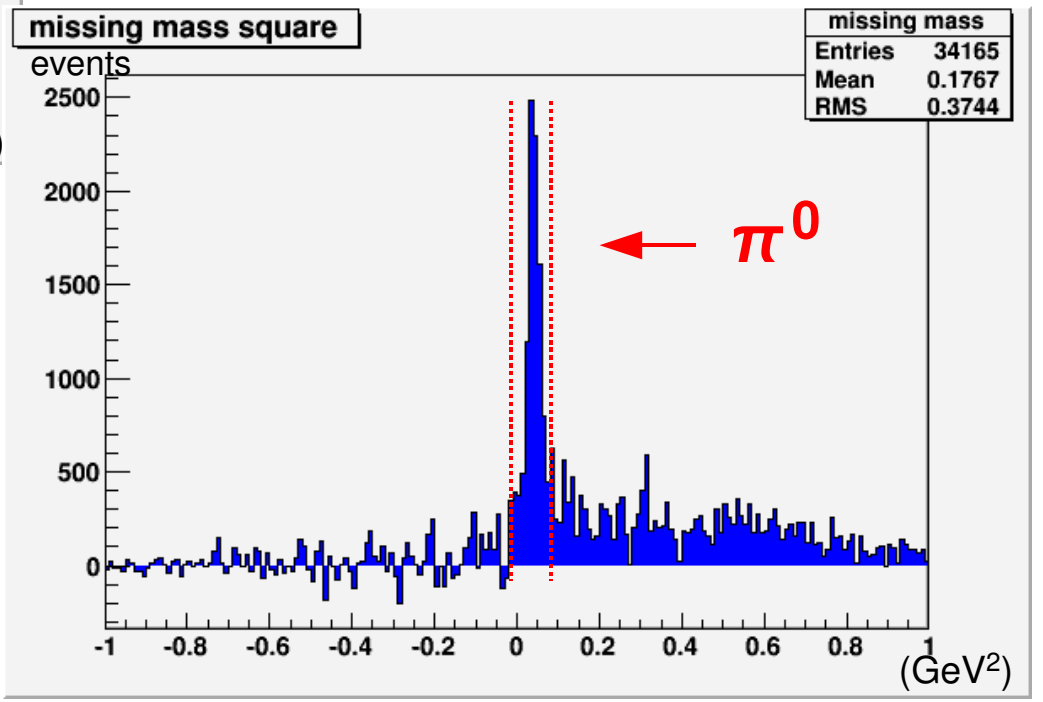


Dilution factor for $\gamma p \rightarrow \pi^0 p$



Dilution factor: max ~ ***0.35***

Subtract normalized carbon from butanol



Helicity asymmetry E for $\gamma p \rightarrow \pi^0 p$

$$E = \frac{1}{D_f P_T P_\gamma} \frac{N_{3/2} - N_{1/2}}{N_{1/2} + N_{3/2}}$$

Polarizations

Beam electron : P_e = 79.8 ~ 87.6 %

Photon : $P_\gamma = P_e \frac{4x - x^2}{4 - 4x + 3x^2}$

Target: P_T = 78 ~ 92 %

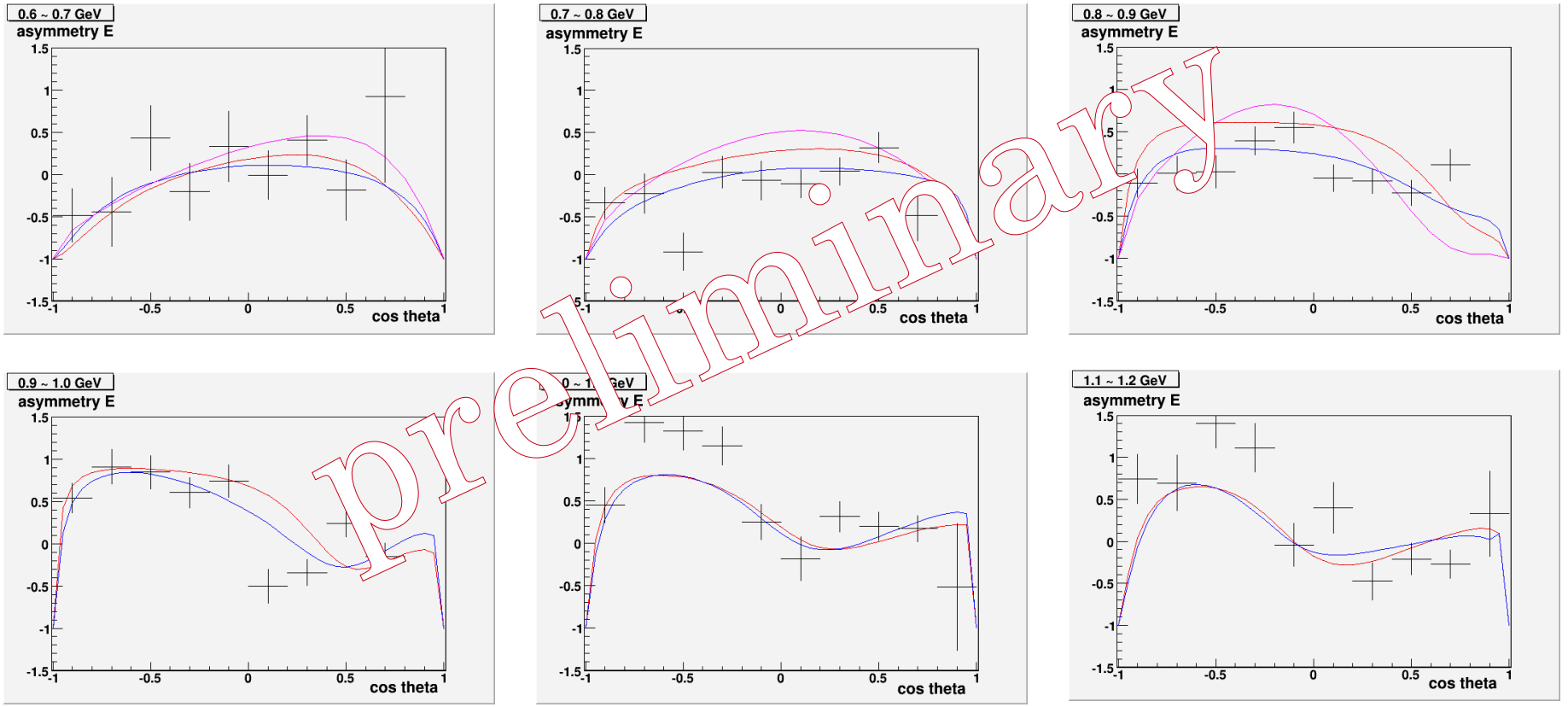
Dilution factor: D_f : max ~ 35 %

Helicity asymmetry E for $\gamma p \rightarrow \pi^0 p$

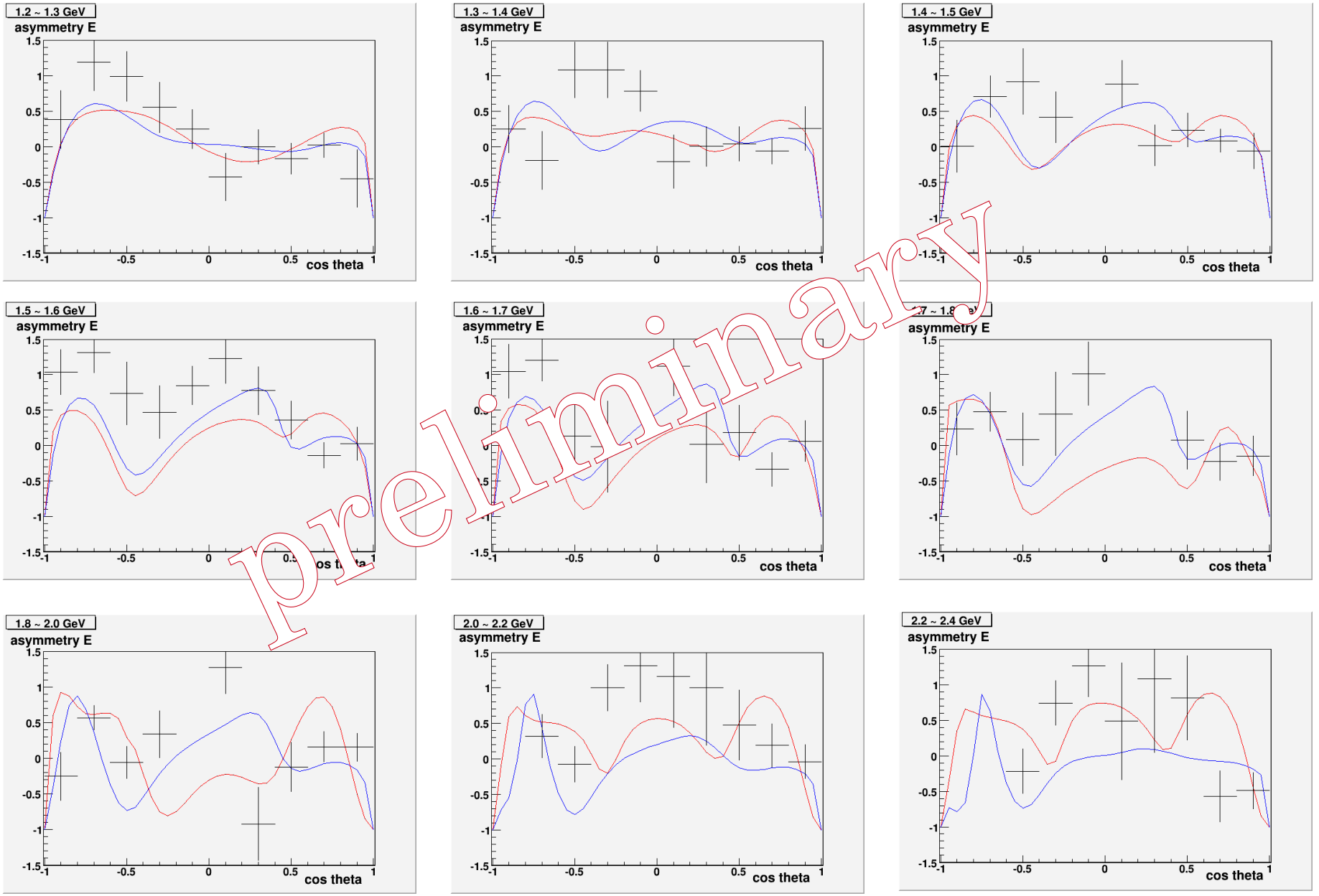
$$E = \frac{1}{D_f P_T P_\gamma} \frac{N_{3/2} - N_{1/2}}{N_{1/2} + N_{3/2}}$$

SAID2009
MAID2007
EBAC

D_f : max ~ 0.35
P_T 0.78 ~ 0.92
Pe 0.79 ~ 0.87



Helicity asymmetry – 2 -



Helicity asymmetry – 3 -

MAMI (Phys. Rev. Lett. Vol. 88 232002)

$E_{electron}$: 855 MeV

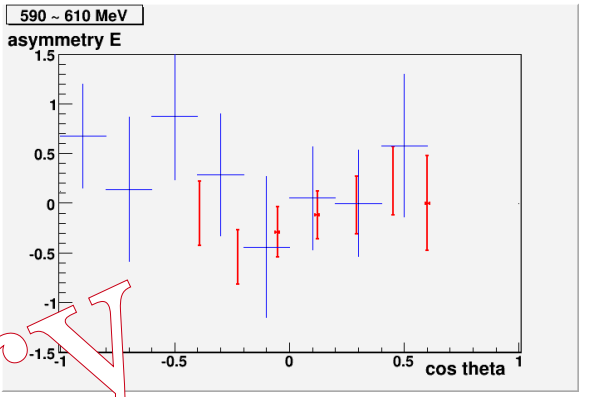
P_T : ~ 0.90

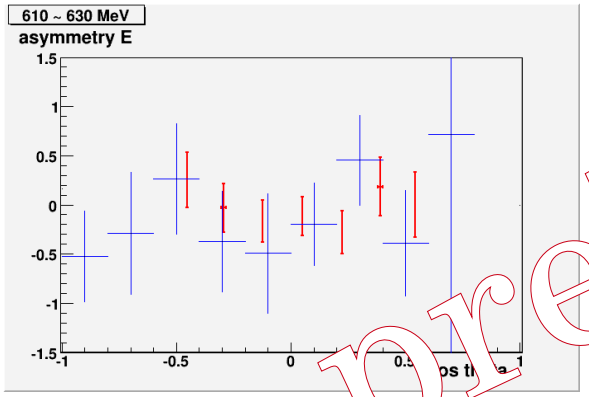
Pe : ~ 0.75

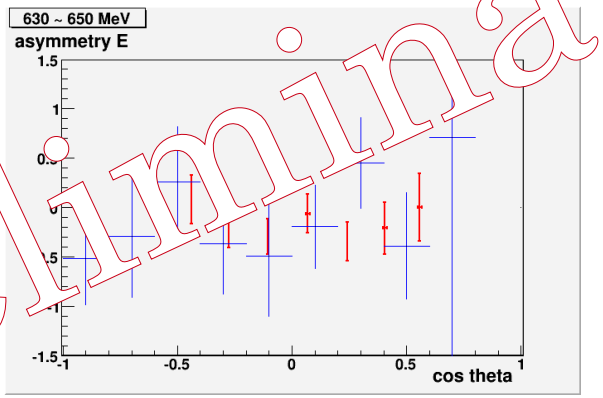
D_f (unknown): 1.0

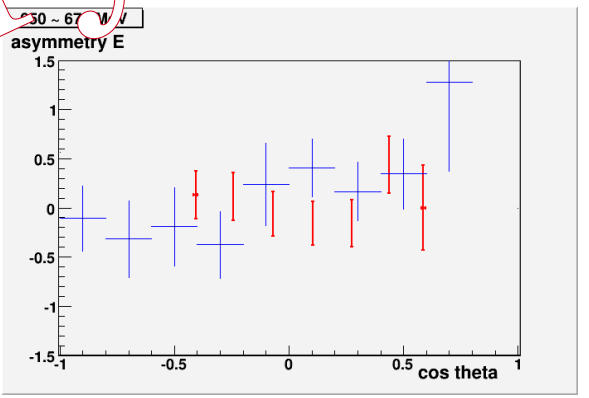
My result

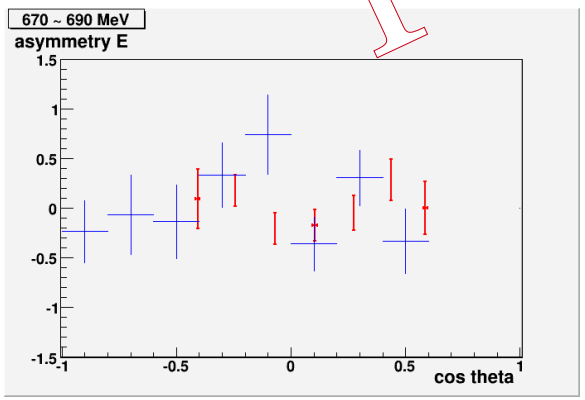
MAMI

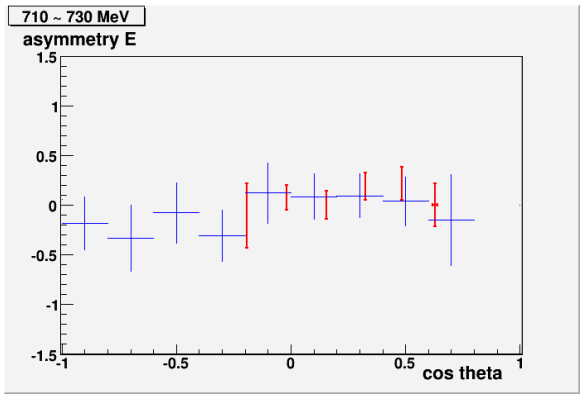


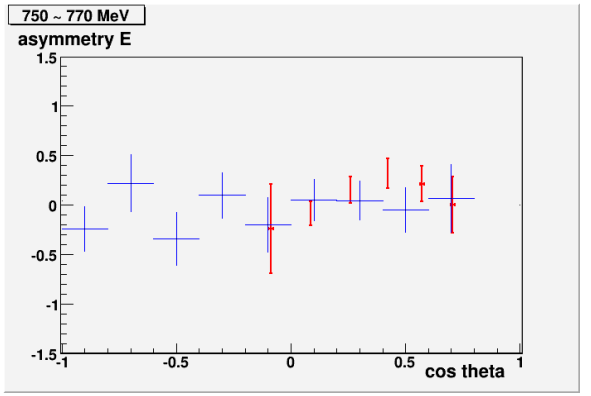












Comment

Preliminary results of E for $\gamma p \rightarrow \pi^0 p$

Improvement

(1) Energy loss and momentum correction because of the holding magnet is not included

(2) Energy of the electron beam is high

for the single pion photoproduction